THE ROLE OF OBJECTIVE FUNCTION IN ENGINEERING DESIGN

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Abstract

The process of material choice is a key element in the production of machines, devices and other engineering constructions. Engineering design relates to the design of engineered artifacts formed by materials of various types. Materials play an important role during the entire design process. At the early design stage, materials may achieve some of the required functions. Therefore, designers may need to identify materials with specific functionalities in order to find feasible design concepts including the costs of material and technology. In this paper, an overview of research in materials identification and materials selection is introduced. The objective function was used in the material selection. The assumed demands in industrial practice were verified by means of criteria patterns.

Keywords: Objective function, engineering design process, materials identification and selection.

1. Introduction

The choice of a proper material for constructions is a very crucial element in a designing process. It is well understood that materials play an important role in engineering design. Materials are generally regarded as the attributes of a physical structure, thus are often considered only after the physical structure of a design that was determined. That is to say, they are often considered after conceptual design stage, such as in embodiment design or detail design. At these downstream design stages, designers need to find materials with specific properties, which can be used to achieve the required system performance and/or other requirements. To this end, the design task is often focused on comparing the properties of a finite set of materials and selecting the best ones out of this finite set, namely, materials selection. Nowadays, the designers have to, apart from materials properties, take into account economic factors such as the cost of usage of such a material, technology costs, costs of influence on environment as well as utilization of post production waste costs.

Fig. 1 presents the relevant information flow associated with key decision-making in the early stages of the design process including economic and environment problems.
At the downstream design stages, the designers may need to determine the material properties, and based on this information, to select corresponding materials. This is to ensure that those system-level design requirements or constraints, such as the performance requirements and economic constraints, can be followed. These design requirements or constraints may be analytically represented. For this we can use objective function. In case of the selection of the proper material for a specific product, having the proper data base of material proprieties, we can create function or algorithm which will make it easier to make the decision.

In the case of the objective function usage additional proprieties can be taken into account by means of partial functions. Partial functions of a goal are responsible for individual factors (material proprieties) needed by designers.

2. The objective function

The purpose of application of generalized objective function is to obtain specific level of mechanical and physical properties in final product, with optimal costs and minimal impact on the environment. When analyzing influence of many factors on properties of being designed detail we encounter difficulties in their assessment since they are the kind of quantities which are in general incomparable and uncountable with each other. In such case, analyzed molecular characteristics should be brought to dimensionless form and there should be applied method of so-called general objective function [1, 2]. Ideological scheme of the method presents Figure 2.

Fig. 3 shows the objective function place in the process of designing and usage of criteria patterns as a checking element.

At the beginning values scope of individual input parameters \( y_1, y_2, \ldots, y_n \) should be transformed into dimensionless selection scale \( d \) with values within the interval (0÷1). This scale expresses relationship between input parameters values \( y_1, y_2, \ldots, y_n \) and corresponding with them values of

![Fig. 2. Scheme of selection function general method](image)

![Fig. 3. Objective function placed in the process of designing](image)
In most practical optimization cases we have to do with single specification limit of input parameters of \( y \leq y_{\text{max}} \) or \( y \geq y_{\text{min}} \) type. In such case, conversions of input value \( y \) into \( d \) are done according to the following exponential relationship:

\[
d_i = \exp[-\exp(-z_i)]
\]  

(1)

where:

\[
z_i = b_0 + b_1 \cdot y_i
\]  

(2)

After conversion and bilateral finding the logarithm of (1) equation is received:

\[
z_i = -\ln(\ln 1/d_i)
\]  

(3)

Coefficients \( b_0 \) and \( b_1 \) can be determined from equations:

\[
z_{i1} = b_0 + b_1 \cdot y_{i1}
\]  

(4)

\[
z_{i2} = b_0 + b_1 \cdot y_{i2}
\]  

(5)

which are determined for two different input values of \( y_i \) parameter which is given appropriate selection values \( d_i \). When solving given system of equations (4) and (5) there are obtained:

\[
b_0 = \frac{z_{i1} \cdot y_{i2} - z_{i2} \cdot y_{i1}}{y_{i2} - y_{i1}}
\]  

(6)

\[
b_1 = \frac{z_{i2} - z_{i1}}{y_{i2} - y_{i1}}
\]  

(7)

In described way there are carried out conversions of value of each input parameter \( y_i \) into dimensionless scale \( d_i \). Having determined selection values \( d_i \) for all input parameters, there is calculated general quality function \( D \) as geometric mean of special partial functions:

\[
D = \sqrt[n]{d_1 \cdot d_2 \cdot \ldots \cdot d_n}
\]  

(8)

The values of \( D \) function belong to the interval \( 0 \div 1 \). The examples of the usage of objective function in the material selection for galvanic layer was shown in the work [8, 9].

3. Criteria standards

Production processes occur in production zone area, in which were previously defined parametric requirements that designed quality in produced object. Criteria standards were applied for selected operations of technological process of pallet level raiser production. Conceptions of using criteria standards are described in work [6]. In research works there were established criteria standards for processes of cutting, welding, punching, bending and electrolytic application of protective coating. In Table 2, there is introduced setting of criteria for process of cutting and coating application. For cutting process there were selected following criteria considering:

- geometric finish,
- economic factors.

In geometric criteria particular attention was drawn to surface smoothness, which has significant importance for the process of applying zinc coating.

For process of electrolytic application of coating under the concept of geometric quality was adopted coating thickness.

Criteria states of group \( F \) (correctness) were calculated for minims (Eq. 9, 10):

\[
W_i = 1 - s
\]  

(9)

\[
s = \frac{k_e - k_i}{k_a - k_i}
\]  

(10)
where:

\[ k_z = \text{temporary measured value}, \]

\[ k_i = \text{the smallest value of given factor}, \]

\[ k_a = \text{the biggest value of given factor}. \]

The criterion state for coating thickness is given by equations 11 and 12 for temporary coating thickness \( k_a = 14 \, \mu m \).

\[ s = \frac{14 - 12}{24 - 12} = 0.166 \]  
\[ W_{pg} = 1 - 0.166 = 0.834 \]  
\[ (11) \]
\[ (12) \]

According to this dependence there were determined all criteria states from F group. Standards from G group are calculated from dependencies described in work [10]. For example non defective \( G_{pb} \) for applying coating process were calculated from dependence 13 for maxims \( W_i = s \).

\[ G_{pb} = \frac{i_{pb}}{i_{pw}} \]  
\[ (13) \]

For process of applying coating non defective is \( G_{pb} = 0.09 \).

Productivity was determined by the ratio of the number of objects produced in real work time unit \( l_{cecc} \) to theoretical \( l_{teo} \) what is expressed by formula (14).

\[ G_{pw} = \frac{l_{cecc}}{l_{teo}} \]  
\[ (14) \]

Material saving is the ratio of final product \( m_w \) and semi finished product \( m_p \). Due to the electrolytic process specificity, mass is calculated for the entire batch of product. Finished product is element covered with zinc coating and semi finished product is raw element and electrolytic zinc deriving from anode.

\[ G_{pm} = \frac{m_w}{m_p} \]  
\[ (15) \]

**Tab. 2**

<table>
<thead>
<tr>
<th>Quality criteria standard of flat bar cutting process and process of coating electrolytic application</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>name</strong></td>
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<tr>
<td>---</td>
</tr>
<tr>
<td>Flat bar cutting process</td>
</tr>
<tr>
<td>Dimensional precision</td>
</tr>
<tr>
<td>Shape precision</td>
</tr>
<tr>
<td>Surface roughness ( R_a )</td>
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<tr>
<td>Surface roughness ( R_z )</td>
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<tr>
<td>Productivity</td>
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<td>Material saving</td>
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<tr>
<td>Process watt hour efficiency</td>
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<tr>
<td>Non defective</td>
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<tr>
<td>Process of applying zinc coating</td>
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<tr>
<td>Coating thickness</td>
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<td>Productivity</td>
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<tr>
<td>Process watt hour efficiency</td>
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<tr>
<td>Non defective</td>
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</tbody>
</table>
Standard criteria were used for all realized processes in pallet level raiser production process. Graphical interpretation of received results is introduced at Fig. 4.

**Fig. 4. Graphical interpretation of determined standard criteria: a) cutting process, b) process of coating deposition.**

### 4. Conclusion

The article presents one of the ways of material selection during the engineering design. Materials identification is a function-oriented and functionalities-centered design activity. It aims at developing feasible or more economic design solutions by using materials of relevant functionality. The condition of the objective function usage is the knowledge of the edge proprieties (such as endurance, hardness) of a material for a given usage. Every needed property can be described by separate detailed function, which enables to take into consideration different factors as one objective function regardless if they are connected with mechanical property or they are the economical factors. The shown way of material selection is used in Wielton Company for the production of specialist trailers. There are also works describing the use of the objective function for eco-designing of multi-layer composite where eco-index 99 is one of them. The use of criteria patterns in the technological process in a simple way enables to identify the divergences between the project assumptions and its practical realization.

Application of criteria standards allowed the analysis of factors group affecting the quality of final product can be graphically expressed in one graph. Applied radar graphs enable analysis of difference between ideal – model and actual process (Fig. 4).

### References


